Norman Borlaug— Hunger Fighter

by Don Paarlberg

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Introduction

Don Paarlberg wrote this article two years ago. His ending paragraph has proven prophetic: "To be a hunger fighter is to work in a cause conducive to peace." The man he so described is Norman Borlaug, recent winner of the Nobel Peace Prize. Dr. Paarlberg writes about the man Borlaug but also describes one way to progressive and constructive change.

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Jean Henri Fabre, the nineteenth century French naturalist, once said, "History records the battlefields on which we lose our lives, but it disdains to tell us of the cultivated fields by which we live; it can tell us the names of the king's bastard offspring, but it cannot tell us the origin of wheat. Such is human folly."

This is a story of cultivated fields rather than of battlefields, a story of wheat, a story of a man who fights the world's hunger and seems to be winning.

The story might begin at some unknown time and place in Asia, where there occurred what would seem a trifling incident, a mutation in an individual wheat kernel, a genetic accident at once violent and delicate. The wheat that resulted was short and stiff-strawed instead of tall and slender. A sharp-eyed Asian farmer noted this strange new dwarf wheat, saved it, planted it, and thus preserved what would prove to be a precious bit of germ plasm.

Or the story might begin in Japan in 1946 when Dr. S. C. Salmon, a life-long student of wheat and an agricultural adviser to General MacArthur, noted this dwarf wheat and brought it to the United States.

Or it might begin in Washington in 1941, when Vice President Henry A. Wallace recommended an expanded agricultural development program to Raymond B. Fosdick, President of the Rockefeller Foundation.

It might begin in the Punjab of 1963, when D. S. Athwal, a plant breeder from India's Punjab Agricultural University, imported and tested various types of new, high-yielding, short-stemmed, disease-resistant wheats from the Western world, touching off a "green revolution" that promises to move mankind out from under the shadow of hunger.

STORY REALLY OPENS IN MEXICO

It might begin with any of a hundred places, times, or people. But the story really begins in Mexico in October of 1944 when Norman Borlaug went to that country for the Rockefeller Foundation to improve its agriculture. There followed a chain of events, partly planned and partly the result of chance, that promises nothing less than the transformation of world agriculture.

Who is this man Borlaug? How did he capitalize on the fortuitous prank of nature and the discerning eye of an Asian farmer? How did he orchestrate the work of the experimenter, the institution-builder, the educator, and the public official? How did he, a Westerner, take the free gift of the East, reshape it, and return it immensely enriched? How did he help the New World discharge its debt to the Old?

Norman Borlaug was born on a farm in northeast Iowa in 1914 near a little town by the name of Cresco. He is of medium size, in his fifties, erect and lean, of

Norwegian stock. There is intensity in his manner and animation in his gestures. His blue eyes widen with enthusiasm as he makes a point. Borlaug's office in Mexico City is decorated with heads of wheat, displayed as someone else would display flowers. His desk is covered with papers; this "filing system" provides instant availability for a large number of documents which he distinguishes from one another by size, shape, color, and markings in the same fashion that he discerns the differences between various strains of wheat in the test plot.

Talking with Norman Borlaug is a unique experience. Ask him about himself and he tells you about his colleagues. Ask him about what he has done and he tells you what he is going to do. Ask him about the Rockefeller Foundation and he tells you about wheat. Ask him about wheat and you won't have a chance to ask him anything else.

Borlaug's conversational comments reveal his thought habits, based on his vocation. "Plant breeding is like poker," he comments. "If you've got a bad hand, throw it in. If you've got a good one, don't be afraid to bet." "Small differences can be decisive," he says. And his intense focus leaves no doubt about his ability to discern these small differences.

Perfectionism? He's not a perfectionist. "Don't spend a lifetime looking for the perfect plant." The contest is the format within which he thinks. "A man has to be a torero, a bull fighter," he says. "He has to sidestep bureaucracy and red tape."

In his high school and college years, Norman Borlaug was a wrestler. His high school coach, Dave Bartelma, had profound influence on him. "Do your best or don't compete," Bartelma said, and he gave his young athlete a code for life. Athletics carried over into college. At the University of Minnesota, where Borlaug did his Bachelor's, Master's, and Doctoral degrees, his team was beaten only once in ten meets. And the spirit of commitment, dedication, and competition carried over into his adult years. From 1941 to 1944, he worked as a plant pathologist in the DuPont fungicide testing laboratory at Wilmington, Delaware. Once he threatened to resign unless he could have freedom to work in the laboratory nights and holidays.

Growing things fascinated Borlaug from his childhood. He always had a feeling for plants, a passionate but undefined desire to know how they grew. Wild plants interested him especially. Why did a certain species grow in one place but not in another? Hunting, fishing, and trapping, standard enterprises for a Midwestern farm boy, were the natural laboratory in which this young scientist first learned the wonder for living things that was to stay with him throughout life.

Forestry was his subject as an undergraduate. Forestry for a young man from the Iowa prairies! After graduation he worked for a time in the "primitive area" of the Salmon River country in the Idaho National Forest. Here he developed the sense of beauty and solitude that had been his from his childhood.

Borlaug's graduate work was in plant pathology. His career carried him into genetics. To follow through his wheat improvement work, he has had to develop good understanding of ecology, soil science, plant nutrition, meteorology, engineering, economics, demography, administration, and group dynamics. How does he now describe his work? "I don't know what I am," he says, with a trace of regret, typical for a scientist who has been pulled out of his original field. But it is perfectly clear what he is; he is an *integrator* of the scientific disciplines in a day when *differentiation* is the fashion. Therein lies the special uniqueness of Norman Borlaug and the reason that he has been able to make a greater contribution to the alleviation of world hunger than any other living man.

MEXICAN AGRICULTURE WAS IN TROUBLE

The Mexico to which Borlaug came in 1944 was primarily an agricultural country, with three-fourths of the people living on the land. In much of the country agriculture was traditional; the state of the agricultural arts had not been greatly changed since colonial times. Fields had been cultivated, some of them for 2,000 years, with virtually no replenishing of soil nutrients. Tillage was done with muscle power, animal or human. Harvest was largely with the hand sickle. Plants and animals were ravaged by almost every known disease. Insect damage went unchecked. Irrigation was used only to a limited degree. Farming had low social status, as was and is true in many countries of the world. For 400 years the ruling practice in Latin America had been to suck up as much as possible of the wealth produced in the countryside and concentrate it in the great cities: Mexico City, Lima, Bogota, Rio, Caracas, Santiago, Buenos Aires. It was in these central cities that achievement was to be measured, not in the countryside. The inevitable result was an impoverished agriculture.

There were efforts, of course, to improve the position of the farm people. In 1854, the National School of Agriculture was founded, located today at Chapingo just outside Mexico City with a present enrollment of 1,200 students. The Revolution beginning in 1910 served to lift the status of the man on the land.

But in 1944, agriculture was still in critically poor condition. Most farmers were illiterate. Per capita rural incomes were but a fraction of those in the cities. Corn yield per acre was eight bushels, compared with 28 bushels in the United States. The per acre yield of wheat was only about three-fourths that of the United States, despite the fact that much Mexican wheat was irrigated and should have yielded vastly more.

Beyond all this, but related to it, was the fact that the numbers of people were increasing at a rate that would more than double the population in the next 25 years. Medical advances, everywhere welcomed, had cut the death rate in half while the birth rate continued undiminished. As a consequence of the population explosion, the food supply was in jeopardy. Imports were rising, asserting a troublesome demand for limited foreign exchange. The foreseeable result, if these trends were to continue, was stark disaster.

To cope with this problem four people were sent by the Rockefeller Foundation. George Harrar, Ed Wellhausen, and Bill Colwell had arrived in 1943, and had begun the work. Borlaug came the next year. The immensity of the problem must have seemed almost overwhelming. Even at its maximum, reached about 20 years after it was launched, the Rockefeller operation in Mexico comprised only 21 U.S. scientists including those working on many crops in addition to wheat.

Borlaug, coming in afresh with Foundation backing, had some enormous advantages. He was free from the political pressures which beset government efforts at agricultural development. He was not troubled by the professionalism that impedes university research. There was no compulsion to show a profit, as is the case in business enterprises. Perhaps most important, Borlaug was free from that handicap of the "short-term" assignment which keeps an agricultural scientist in a country just long enough to gain some understanding of the problem but not long enough to make a major contribution.

He had real advantages. How should he use them? Some self-appointed counsellors would have had him forego the use of these advantages and proceed in the same fashion as the other development people. Some, the "necessary prior condition" advocates, discounted the possi-

bility of doing *anything* until certain conditions had been met:

> "First a comprehensive agricultural development plan must be prepared," or
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> "First we must have answers to a number of basic scientific questions," or
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> "First the people must be made literate," or
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> "First the educational institutions must be made over on the model of the American system," or
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> "First we must complete the land reform."

These counsels of conformity or of perfection or of inaction were all rejected. Instead, Borlaug set up a program with these unique features:

- Priorities were established, *and adhered to.* The number-one priority was to improve wheat yields so as to feed hungry people.
- No distinction was made between basic and applied science; emphasis was on whatever was needed to advance toward the program objectives.
- Career scientists were placed in charge and given *long-term assignments.* Native young people were trained through internships and outstanding men were given advanced study with the purpose of preparing them to take over the program. Borlaug's idea was for the Foundation to "work itself out of a job."

The criteria for success were increased *productivity* and increased *profitability.* The emphasis was on action and on results. Red tape was minimized. Borlaug's scorn for the paper shuffler is vividly indicated by his comment: "We need to develop a mutant strain of man who will have the enzyme cellulase in his gut which will thereby permit him to eat, digest, and grow fat on the mountains of paper and red tape that are being produced in ever-increasing abundance by the world's planners, bureaucrats, and press."

Relations with the Mexican government were cordial from the first. The original venture was made at the request of government officials. Testing facilities were made available at the national agricultural college at Chapingo, just outside Mexico City. Cooperation with the government extension service began early and continued. One precaution was observed; the Mexican government must remain sufficiently distinct from the program so that failure of some program venture, if it occurred, would not implicate the government. And vice-versa! Only by keeping the relationship loose could the independence of the program be assured.

Good relationships were also established with other agencies: the Ford Foundation, the Food and Agriculture Organization of the United Nations, the U. S. Department of Agriculture, and the U. S. land-grant colleges of which Borlaug was a product. But the same strict rule was followed: no ties that would restrict the autonomy of Borlaug's operation.

A question immediately arose, a question that confronts everyone who works at agricultural development. Should the work be in sharp focus, directed at a particular crop or, even more sharply, at some particular problem of that crop? Or should it be broad, concerned not only with production but with marketing, processing, and the whole battery of supporting services which the development planner calls by that bureaucratic name, "infrastructure"?

Borlaug decided to begin with a particular crop, wheat, and with a particular problem of that crop, the fungus disease known as rust. His belief, verified by later developments, was that if he could lift the potential yield of wheat, other things would follow. Farmers would be motivated to buy fertilizer, would see the necessity of better marketing facilities,

and would force the adoption of other needed changes. The private trade would be induced to supply services that the improved wheat would make profitable. In the first place, he lacked the resources to lay out and follow through a complete blueprint for agricultural development. He was not an agricultural development planner; he was a plant pathologist. In any case, the farmers could not visualize the need for Step 2 until the results of Step 1 were in hand. Thus, whether through foresight, accident, or lack of resources, Borlaug avoided the elegant but often ineffective overall development design that so fascinates the central planner.

CHOSE WHEAT, THE STAFF OF LIFE

Borlaug chose to work first on wheat. Why wheat? Because it was important, the staff of life. Mexico had to import 10 million bushels a year, more than half her supply, requiring the use of much needed foreign exchange. And Borlaug even in those early days had his eye on the rest of the world. Wheat is the widest grown crop of all. More people rely on wheat as their staple food than on any other crop except rice. Wheat is nutritious, palatable, low in cost, virtually free of taboos, storable, and in every way a superb weapon against hunger. If Borlaug could improve Mexican wheat, there was the chance that he might help wheat-eating people in the rest of the world.

Clearly there was plenty of work to do. Wheat yields were abysmally low; the national average was less than 12 bushels per acre. Technology was poor. Wheat varieties were numerous and enormously varied. According to tradition, most Mexican wheat is derived from a few grains sorted out of a shipment of rice by Juan Gattido, who landed with Cortez back in 1519. Hardly a scientific choice of wheat variety!

The first thing Borlaug did was to gather as many of the Mexican wheat varieties as possible, from various altitudes and latitudes. The work was done in cooperation with B.B. Bayles of the U.S. Department of Agriculture. Altogether, some 8,500 individual head selections were made from farmers' fields in different parts of Mexico. Selections were tested, not just in one location, but in many:

- Obregon, in the "new" wheat region of Sonora, far to the northwest, along the Pacific Coast.
- La Cal Grande, in the "old" wheat region west of Mexico City.
- Torreon, to the north, in the Laguna region.
- Chapingo, Toluca, and Mexe, in the Mexico City area.

His findings:

All the varieties were naturally slender and inclined to be tall. This was a natural thing. Farmers around the world have traditionally selected seed from plants with the highly visible attribute of tallness, associating this, often incorrectly, with vigor and productivity. Recall the prideful old song, "Iowa, Iowa, that's where the tall corn grows!" Modern Iowa farmers still sing the song, but they have now learned to buy seed that produces short, sturdy, high-yielding plants.

None of the varieties was capable of using heavy applications of fertilizer. All had gone through countless generations of natural selection in which they had become adapted to the worn-out soil. When fertilized they grew tall and rank; with wind and rain they fell flat on the ground. Thus more fertilizer often meant *less* grain per acre.

The native Mexican wheats were generally susceptible to rust, a fungus disease that saps the vitality of the plant, clogs the passageways from root to blade, sucks out the plant's moisture, and covers stem and leaves with a growth that reduces the effective leaf surface. A field afflicted

with the disease appears soiled, tarnished, and "rusty," hence the name. The disease spreads by releasing tiny spores, brown, red, or yellow depending on the species, carried by the wind for hundreds of miles. One acre of well-rusted wheat may have as many as 50,000 billion of these spores. They rise in clouds at harvest time, settling on man and machine in a fashion repulsive to eye and spirit. The grain from a rust-infected field is shriveled and shrunk. A severe case of rust can cut the yield in half or even reduce it to zero.

Only two out of Borlaug's 5,000 bread wheat selections showed resistance to rust. And there is no assurance that a resistant variety will continue to be resistant. Rust, like wheat, may undergo mutation, a genetic change. The mutant form, called a new race, may permit the rust to overcome the wheat's power of resistance. To maintain rust resistance is a great battle, calling for substantial continuing effort. It is as Alice in Wonderland, who had to run fast to stay where she was.

It was clear that until the rust problem was brought under control, no real progress would be possible. So began the program to breed wheat for rust resistance. This involves crossing or hybridizing, an arranged marriage, the manipulation of germ plasm that permits the designing of plant varieties in a fashion similar to the designing of industrial products. The assumption in crossing is that the desired plant characteristics exist somewhere, perhaps masked or hidden, in some strain of wheat. The objective is to find them, lift them out, and combine them with other desired features in a new useful form. The crossing required to achieve this result is a delicate operation, performed with tweezers and magnifying glass.

The wheat that results from the first planting of a cross may look like either of the parents, or may be intermediate and

look like a new variety, depending on its inheritance. When its seed is planted to produce second-generation plants, many different types may appear. No two plants are identical in the second generation. The plant breeder selects the superior ones, using as his criteria such attributes as disease resistance, yield, baking quality, drought tolerance, maturity, standing ability and so on. Less desirable plants are discarded. The plant breeder keeps selecting and discarding for about six or eight generations, by which time the new variety takes on considerable uniformity. It is then increased and tested on a larger scale in various regions. The whole process takes about 10 years; if two crops a year are grown, the necessary time can be reduced by half.

Once the process of selecting and discarding has been completed, the resulting hybrid remains fixed in its genetic composition. While the crossing of wheat is difficult and delicate, the lasting results make multiplication of the new variety both rapid and low in cost. It was this character that made possible the speedy expansion of improved wheats throughout Mexico and eventually overseas.

Over a period of 20 years, Borlaug and his associates made more than 30,000 of these wheat crosses and tested the results. The choice of which to retain and which to discard is in part a matter of scientific testing and in part intuition, an attribute with which Borlaug is especially endowed.

The two Mexican lines that had shown resistance to rust were crossed with the more promising of the other lines. In addition, there were crosses with rust-resistant wheat introduced from the United States, from Kenya, from Australia, and from Morocco. Some of these crosses produced wheat that had a fairly high degree of rust resistance.

Borlaug came to the conclusion that his improved wheat should not be highly specific in its adaptation. Mexico has a multitude of microclimates and ecological conditions. Variations in moisture, temperature, latitude, altitude, fertility, and tillage practices are very great. To try to tailor a specific and different wheat for each particular circumstance would be an impossible task. So Borlaug set about to develop a limited number of wheat varieties with general rather than specific adaptation. It was this approach, whether instinctive, fortuitous, or deliberate, that permitted the rapid spread of his wheat not only within Mexico but outside the country, from Morocco to India.

Another favorable event resulting from an unknown mix of good planning and good fortune was the development of wheat varieties that were non-photoperiod-sensitive, or perhaps more understandable, light-insensitive.

What causes plants to come to flower and mature? Why will a crop planted two weeks late mature only a few days later than the crop in the neighboring field that was planted on time? There is in plants and animals a marvelous and delicate capability for responding to the length of a day. By this device, wild plants, which are without man's help, adjust themselves to their environment, through evolution. The wonder of this reaches most beyond the scientific.

Borlaug bred photoperiod-sensitivity out of his wheats. He came up with wheats that utilize the same number of days to maturity regardless of whether the hours of daylight are lengthening or becoming shorter. This was an enormous gain. If wheat is light-insensitive and if moisture and temperature permit, a farmer in or near the tropics perhaps can get two crops a year, which nature never intended. And the wheat will be adapted within a latitude of perhaps 5,000 miles instead of 500.

And that is the kind of wheat Borlaug got—light-insensitive, suited for multiple-cropping, adapted throughout the whole

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country of Mexico and, as we shall see, to much of Asia, Africa, and Latin America as well.

Closely built into his wheat research, Borlaug had a trainee program resembling an apprenticeship arrangement. Over the years, some 100 young scientists from 22 nations participated in his program, learned his methods and absorbed some of his enthusiasm. They slogged through the mud, choked on the dust, withstood heat and cold, mastered delicate skills, learned the meaning of scientific integrity, and, perhaps most important, learned the dignity of manual labor. They returned to their countries, often carrying the new wheat varieties with them. These were "the wheat apostles," who laid the groundwork for the later rapid expansion of the Mexican wheats.

Borlaug approaches building a team of wheat scientists the same way he has successfully coached and built athletic teams. He believes in teaching fundamentals and then insisting on the individual mastering the technique. This, amply mixed with the will to win, builds championship teams, whether in wrestling, baseball, or wheat improvement. He introduced Little League, Pony, and Colt League baseball to Mexico, to provide an opportunity for his only son, Billy, to learn to compete. Borlaug coached twelve teams over a period of six years, winning 11 league championships and one National Mexican championship.

Most of the major decisions Borlaug made seemed to be guided by a strange sense of destiny, preparing his wheat for its world role. The many sources of germ plasm, the use of many different testing sites, his choice of a rapidly multiplying crop of fixed genetic character like wheat

in the first place, the close association with young trainees from various countries—all of these made it easy for his wheat, once it had been developed, to spread quickly within Mexico and then abroad.

The wheat-breeding techniques used in Mexico were not designed by Borlaug. What was unique was the execution of the plan, the adherence to the goal, the depth of his commitment, and the continuity of personnel. All of this plus the serendipity that somehow seems to attend the bold and venturesome.

MEXICAN FARMERS ACCEPT THE WHEAT

Now that this new wheat was developed, how would he get the farmers to accept it? No problem. Borlaug had been working on this from the first. Four years after his work began, he showed his results to the neighboring farmers. Five farmers showed up for his first field day at his test plots in the Valle del Yaqui in Sonora. As research results became available, interest grew. Within three years there were hundreds of farmers attending his field days. Within eight years there were thousands, and they came from all parts of Sonora and from three neighboring states. These were the farmers said by some to be apathetic, disinterested, and disinclined to change.

In fact, the farmers forced Borlaug to release his wheat before he had intended. One day, after his work was well-advanced, he was showing his test plots to the neighboring farmers. They were impressed by the vigorous appearance of the ripe standing wheat and swarmed into the test plots, plucking the heads and stuffing them into their pockets for seed stock. Rather than accept this kind of unplanned distribution, Borlaug released his wheat.

The myth that illiterate farmers resist efforts to improve their lot comes, often, from offering them things that are of no advantage to them, or, at least, no perceived advantage.

Throughout these years, Norman Borlaug's commitment became completely clear to his associates. The science had to be good, but that wasn't enough; it had to be good for something: "To help put bread in the bellies of hungry Mexicans." Interrelationships were clearly seen. "The wheat program was to be in a package deal. We can't get anywhere if we split it up into a lot of splinter programs." Priorities were clear. "We can't wander off on a lot of scientific sideshows or go chasing academic butterflies; we have to do first things first." A number of stories grew up, some of them no doubt apocryphal. Once, after a hard day's drive, nearing a town where they had an experiment station, Borlaug said, "How about going over and taking a quick look at the wheat plots?" His companion responded, in some amazement, "Tonight? It's way after midnight! We can't see the wheats now!" "There's a good moon," said Borlaug. "We could at least see what the plots look like." And they did.

"FIND THE GOLD NUGGETS!"

They worked hard. In a single season Borlaug's crew made from 2,000 to 6,000 individual crosses. Each year they studied the performance of 40,000 varieties and lines, in various stages of development, most of which were planted in several locations. Planted end-to-end, his rows of wheat would have stretched 400 miles! And they studied these tests carefully. "Some of these kernels may be gold nuggets," said Borlaug. "Find them!" Finding them was a case of meticulous selection and ruthless discarding. In 20 years of work with their 40,000 lines, they created and distributed some 75 new varieties, of which four subsequently comprised the bulk of the wheat grown in Mexico.

Borlaug insisted on accurate observa-

tion. Sophisticated analysis was no substitute for good raw data. Electronic computers were fine, he said, so long as they were properly programmed with accurate information. He advocated a new computer model with a gadget in its belly containing "a compound as vile-smelling as the stomach of a camel, automatically governed so that it would regurgitate in the face of the operator, programmer, and scientist when it is fed bad data."

Another battle Borlaug had was with the statisticians, who at one stage threatened to impose rigid standards on the results of all research work. Though many scientists succumbed to this domination, Borlaug, while using the best of statistical tools, nevertheless insisted on retaining considerable latitude for personal judgment.

Borlaug continued to use effective and efficient laboratory equipment even though more expensive and prestigious tools had been invented. For him results were always the test. Method always stood in service to the objective. His purpose was to overcome hunger, not to impress his colleagues. He was still at heart the competitor-athlete, calling the signals in his war on hunger. "Deafness to criticism," he once said, "is a valuable trait for the scientist quarterback."

Using these techniques, attitude, and methods, Borlaug pushed on. By 1951 it began to look as if the battle against wheat rust had been won. The disease seemed checked by the resistant varieties. Then suddenly appeared Race 15B, a type of rust previously of little importance. It spread throughout Mexico, the United States, and Canada with explosive force, ruining fields that promised 40 bushels an acre. Race 15B was deadly to two of Borlaug's four varieties, but the other two came through well. Reliance was shifted to these varieties and the new threat passed.

In 1953 another variant of rust, Race 139, arose to strike down the remaining two of his established varieties. A series of new crosses, using lines carried in the wheat nursery, produced the resistant Chapingo 52, Chapingo 53, Bajio, and Mexe. These resisted the new rust and provided the basis for his successful updated varieties.

RUST DEFEATED

By 1957, thirteen years after his work began, Borlaug was able to say that he had the rust problem under control. A number of new lines had been released; 70 percent of area cultivated to wheat was seeded to these new varieties. The national average yield had been increased from 11.5 to 20 bushels per acre as the depredations of the rust had been checked. This was success, unprecedented and unquestionable.

Had Borlaug been only a pathologist, which was the area of his training, he might have congratulated himself on a job well done and tapered off his work sometime during the 'fifties. He would have kept some work going to keep ahead of such new races of rust as might develop. He could have had a sinecure for the remaining years of his professional life and congratulated himself on staying within his profession.

But not Norman Borlaug. He saw the big picture; he subscribed to the primary objective, which was wheat improvement. Part of the job was done, or well on the way to being done. For a lesser man this might have been the occasion for retiring on the job. For Borlaug, it was an open door to the real objective.

Yields were still low. Soil fertility was limited and the capacity of his wheat varieties to take up soil nutrients was likewise limited. Soil fertility could be increased with fertilizer. But Borlaug's wheats responded by growing tall and lodging, falling flat with rain and wind rather than producing more grain. A small application of fertilizer helped some. But

beyond that point, the more fertilizer the lower the yield.

What was needed was germ plasm, from somewhere, that would permit the wheat to assimilate a large amount of soil nutrients and convert these nurtients to grain, standing stiff and erect in doing so. These attributes had to be capable of being incorporated into his adapted rust-resistant Mexican wheats. He had no such germ plasm. Where could he find it? It had been necessary to go outside of Mexico to get genetic material that would resist rust; evidently he also had to go outside of Mexico to get germ plasm capable of high nutrient intake and high yield.

THE GIANT DWARF

From Japan came this last major component of Borlaug's miracle wheat. Japan is short on tillable land and long has had to use its limited acreage intensively. Hence heavy fertilization had long been the practice, particularly with night soil, the polite term for human wastes. S. C. Salmon, a scientist from the U. S. Department of Agriculture, was in Japan with General MacArthur immediately after the war, helping get that country back on its feet. He noted, in 1946, that the Japanese farmers were growing a number of remarkably stiff, short-stemmed wheat varieties. When heavily fertilized, these varieties stayed erect and gave good yields.

At the Morioka Branch Experiment Station in Northern Honshu, Dr. Salmon first saw Norin 10, which he thus described:

> "It had been seeded in rows approximately 20 inches apart in accord with the Japanese practice and on land that had been heavily fertilized and irrigated. In spite of these very favorable conditions for vegetative growth the plants were about 24 inches high, but stood erect. They produced so many stems and there were so many heads, a second look was necessary to verify the fact that the rows were 20 inches apart instead of the common 6 to 10 inches in the United States."

The short-stemmed Norin wheats have as many leaves and, hence, as big a manufacturing surface per stem as the other wheats. The difference is that they have shorter intervals between the leaves. They waste less effort in erecting an unproductive stalk. And they have many more stems per plant. Furthermore, and extremely important, the Norin wheats have the capacity to take up large amounts of soil nutrients and convert them to grain.

The word "Norin" is an acronym made from the first letter of each word in the romanized title of the Japanese Agricultural Experiment Station. According to Dr. Torao Gotoh of the Japanese Ministry of Agriculture and Forestry, the Norin wheats are derived originally from Daruma, a native wheat named after a kind of short, squat, Japanese tumbler doll. How and where Daruma originated must remain a mystery. Native short-strawed wheat varieties are found throughout Japan, China, Tibet, and Korea. Japanese plant breeders had crossed Daruma with an American wheat (Fultz). The resulting hybrid was later crossed with another American variety (Turkey Red), producing the Norin wheats.

The American varieties had originally come from Asia. Wheat, which may be the oldest domesticated crop of all, is thought to have originated somewhere in the Middle East, close to where man himself originated. From there it must have been carried all over the world, its dispersion in step with that of the men it nourished.

Sixteen varieties of Norin were made available to American wheat breeders in 1947-48. Orville A. Vogel, a wheat breeder of the Agricultural Research Service of the U. S. Department of

Agriculture, stationed in Washington State, was the first to recognize its worth and to use it in a breeding program. Vogel discovered that the Norin wheats, under American conditions, had many faults. They crossed promiscuously with adjacent plants. They seemed susceptible to all our diseases. The timing of the wheat sprout was wrongly triggered; it began unfolding before it reached the surface of the ground. Vogel went to work on these defects, and eventually overcame them. He discovered, to his great satisfaction, that the short-strawed character of Norin 10 was readily transferred to the offspring when crossed with other varieties. In the late 1950's he released famous Gaines wheat.

But long before Gaines wheat was born, news of the new short-strawed germ plasm reached Norman Borlaug in Mexico. As always, he had his antennae up for anything new or promising. He obtained some of the early crosses and breeding lines from Vogel in 1953. Working with his now well-developed techniques, Borlaug crossed Vogel's wheats with his Mexican varieties, obtaining the desired adaptation, disease resistance, and short straw. He found, and words cannot express his jubilation, that the increased yield potential of the new dwarf wheat was due not only to its non-lodging characteristic but also to its greater number of stems, the greater number of grains per head, and its better grain-filling qualities. Furthermore, since the varieties he developed were non-photoperiod-sensitive, they had wide adaptability and were capable of being grown in most of the tropical and sub-tropical wheat-producing countries of the world. Growing two crops a year, Borlaug had two varieties, Pictic 62 and Penjama 62, ready for release by 1961, eight years after he first received the parent stock.

The new dwarf wheats had such voracious appetites for soil nutrients that they pushed far beyond the known range of fertilizer application. So new research had to be done. Optimum nitrogen application for the old wheats had been about 40 pounds per acre; the new wheats made efficient use of 120 pounds. Increased amounts of phosphorous and potash were also needed, as were some of the minor elements. Balancing the diet for these new wheats required an immense amount of research in soil fertility and plant response, which Borlaug and his colleagues readily incorporated into the work of the Rockefeller project, along with pathology and genetics.

The new wheats were so prolific that all kinds of undertakings, previously unprofitable, became paying practices. Weed control, for example. And use of insecticides. And additional irrigation. Borlaug moved into these areas with his research, readily stepping from one scientific discipline to another, invading fields thought to be the special reserve of this or that subdivision of science, disregarding "keep off the grass" signs erected by scientific protocol. He was more concerned with how much hay he put up than with how much grass he kept off of. He was mission-oriented. Looking back on his work, Borlaug said: "Over the years I have evolved a deep impatient interest and drive to bring together the research findings from all scientific disciplines and to formulate them into dynamic wheat production programs."

Once he got the practices orchestrated, yields of these wheats were phenomenal. Better farmers, using improved methods, were able to get yields as high as 105 bushels per acre, two and a half times as high as top yields with Borlaug's earlier varieties. In 1965, Borlaug could say, "The impact of these varieties has been so great that in four years they have taken over 95 percent of the area cultivated to wheat in Mexico." The wheat was so attractive to farmers that virtually all of the first crop and much of the second was used for seed. National

average wheat yields per acre, which had almost doubled from 1943 to 1957, increased another 10 bushels by 1963. Eleven and a half bushels per acre, national average, in 1943; 30 bushels per acre in 1963! From a wheat deficit of 10 million bushels, half her needs in 1943, Mexico now provided the wheat for a larger population and fed them better.

And what of his old wheats, on which he had lavished so much love and labor? Discarded! Just as a quarterback changes his game plan to capitalize on some unforeseen opportunity and just as a General changes his tactics to exploit an advantage, so Borlaug shifted to the new dwarf wheats and scrapped the varieties on which he had labored so hard for 20 years.

Everything Borlaug had done, seemingly, worked together for good. Broadly based disease resistance, varieties insensitive to day length, the readily evident superiority of his wheat, the speed with which it could be multiplied, the readiness with which it could be adopted, the trained apprentices who spread the word, together with an immense resource of good-will earned by his years of devoted labor—all of this catapulted his wheat into rapid adoption.

THE BREAKTHROUGH

This was a breakthrough, a quantum leap, an event unusual in agriculture, where advances typically are gradual. And the breakthrough in genetics touched off revolutionary changes elsewhere. As it became clear that the new wheat would make fertilizer pay fabulous returns, fertilizer use trebled in a single year. The use of insecticides and herbicides was stepped up. Irrigation increased. Storage and transportation expanded. Businessmen stepped forward to service the new needs. Researchers on other crops caught a new vision, now that wheat had experienced this great success. Extension men, working on adult education with Mexican farmers, now had something meaningful to push. Consumers bought increased amounts of the now-abundant wheat, and upgraded their diets by substituting wheat for corn in their tortillas. The Mexican Government felt satisfaction in the improved food situation and took pride in its part of the program. Agricultural development people throughout the world noted the Mexican success. An International Rice Research Institute, modeled on the Mexican wheat experience, was set up in the Philippines. There came a parade of visitors to the Mexican project.

There were several things about this breakthrough that make it special, gave it particular significance.

It came in the hungry part of the world, not in those countries already surfeited with agricultural output.

It came in the tropics, which had long been in agricultural torpor, not in the temperate climates, where change was already occurring at a pace more rapid than could readily be assimilated.

It produced new knowledge and technology that could be used by farmers on small tracts of land, rather than being, like many technological changes, adaptable only on large farms.

It was a breakthrough that came voluntarily, up from the grass roots, rather than being imposed arbitrarily from above.

And what of Norman Borlaug, amidst all this success? The banquet circuit, honors and awards, and well-earned applause of his peers? He had little time for these things. He was already looking to Asia, Africa, and Latin America where he hoped to transplant his new wheat.

* * *

And the need for his new wheat was prodigious. The balance between man and his food supply was being threatened. With the world population explosion, the

danger of hunger, never distant in much of the world, took on a new and harsh immediacy. Malthusian thought was reawakened.

In 1798 the Reverend Thomas Robert Malthus, English pastor and economist, published what he called "An Essay on the Principle of Population." Malthus' main point was that while the food supply tended to increase by an arithmetic ratio (2, 4, 6, 8, 10), the population tended to increase by a geometric ratio (2, 4, 8, 16, 32). No great mathematical insight is needed to see that if this is indeed the case, the population will press constantly on the food supply and that hunger is the natural lot of man. The Reverend Malthus so concluded.

Immediately there arose a great contention. Siding with Malthus were many biologists and economists. Opposed to him were a number of theologians and the vast majority of good-willed citizens whose sensibilities were offended.

Some years after Malthus wrote, a number of new developments occurred. The American agricultural midwest opened up, as did other new parts of the world, pouring out a great flood of farm products which were exported to Europe in exchange for the manufactured articles produced by growing industry. Contrary to Malthus' theory, the food supply increased more rapidly than the population. Hunger, at least in the parts of the world familiar to the Europeans, was in retreat. Malthus was discredited and with the passage of time his teaching took up less and less space in the economic textbooks. Meanwhile, of course, unknown or ignored by the industrialized parts of the world, the Malthusian principle was at work in Asia and Africa.

In the twentieth century medical science made enormous strides, not only in the already developed nations but throughout the world. Death rates were cut in half, while birth rates continued high. The result was the well-published population explosion, which doubled the world population from 1900 to 1960 and threatens to double it again by the year 2000. Malthusian thought experienced a revival; "neo-Malthusians" took over the rostrum and the printing press. Concern about the ability of the earth to feed its people reached a crescendo with the poor wheat crops, especially in India, of 1966 and 1967. The President of the United States instructed his Science Advisory Committee to study the world food problem. The Food and Agriculture Organization of the United Nations pushed its campaign against hunger. The Paddock brothers published a widely read book, *Famine 1975!*, contending that famine on a vast scale was inevitable, and counseling that efforts to avert it be restricted to certain areas that promised some hope of success. India was written off as beyond hope.

In India and in Pakistan, agricultural practices had changed but little for centuries. It was much as it had been in Mexico. The two Asian countries were experiencing more than their share of the population explosion, and had been barely meeting their food needs by importing increasing amounts of American wheat under the Food for Peace program. But this was a policy that could not continue indefinitely. A bond of dependence would place in jeopardy both giver and receiver, the receiver because of uncertainty that the gift would continue, and the giver because to terminate the program would be to assume the onus of causing widespread starvation.

It was with this grave problem that India and Pakistan were struggling. They sought to improve their own food production rather than to become permanent wards of the United States.

It was in this climate of opinion that Borlaug's new high-yielding Mexican wheats began to appear in the Asian subcontinent. The timing could not have been more propitious. As before, Bor-

laug's work seemed the product of benevolent destiny, though on close analysis it appears that destiny undertakes few ventures of her own; she awaits the actions of the bold and courageous.

In 1963, government officials of India and Pakistan invited Borlaug to visit those two countries. This was his second visit; many more were to follow. At Lyallpur, Pakistan, he found a number of wheats from Mexico—brought to Asia by two Pakistani trainees who had been with him in Mexico. These two young men, Manzur Bajwa and Noor M. Chaudhry, had grown and observed these wheats at Lyallpur since 1961. The wheats looked rather ordinary; the research administrators had not permitted the rates of fertilization and the cultural practices suited to them, insisting on the standardized treatment. But the young men had been able to avoid the regulation; they purposely mislabeled one of Borlaug's wheats, planted it in an obscure corner of the test plot, and applied 120 pounds of nitrogen instead of the authorized 40 pounds. The result was phenomenal. As soon as the performance of the Mexican wheat was noted, Pakistan ordered 200 kilograms and India 300, sent by air.

In 1964 these wheats were planted, experimentally, in various locations in both countries. Borlaug sent Dr. Glenn Anderson, wheat expert from the Canadian Department of Agriculture, to help with the project in India. Dr. Ignacio Narvaez, native Mexican and one of Borlaug's earliest and most talented wheat apostles, was sent to Pakistan.

Despite poor fertility practices, results were good. India ordered 250 metric tons from Mexico for the following year, and Pakistan 350. This was to be seed stock from Mexican commercial fields, not from test plots.

Borlaug went to work assembling this shipment. Harvested, cleaned, and loaded, the shipment amounted to 35 truckloads. But now a problem arose. The letter of credit to pay for this seed was deemed by bank officials not to be in good order (three words were misspelled!) and payment was held up. About $170,000 was involved. Suppose the wheat were sent and the money never arrived? "I decided to take the risk and go ahead," says Borlaug. "It was the best decision I ever made in my life."

In July of 1965 the convoy set out from Sonora, Mexico, bound for Los Angeles. This was at the time of the Watts disorder. On its way to the harbor, the fleet of trucks got caught in the traffic tangle and barely reached the dock before the ship left. But now came a new problem. The 1965 War between India and Pakistan broke out while the ship was at sea and the rumor arose that when it docked at Bombay, India would confiscate Pakistan's part of the cargo. To avert this hazard, all the wheat was unloaded at Singapore and transhipped to India and Pakistan in separate vessels. Another difficulty appeared. As a result of improper fumigation and handling, much of the wheat had lost its ability to sprout. The Indians and Pakistanis planted the wheat at regular rates. It came up thin on the ground, an extremely poor stand, 7,000 acres in India and 10,000 in Pakistan. But each plant tillered out, sending up many stems so that at maturity it seemed almost a full stand.

With the experience of Mexico as a ready resource, a plan was developed. Half the wheat would go for commercial increase to make more seed available the following year. The other half would go for demonstrations, planted in small plots by hundreds of farmers. Seed wheat was distributed in small packets to the farmers, who were eager to cooperate. Meanwhile, breeding work would go forward at the experimental farms. And there would be a step-up in the training of young scientists. The extension service would pitch in. Amazingly, about 80

percent of the research work done in Mexico proved to be directly transferrable to Asia.

TALKS BIG AND DELIVERS

"What we have done in Mexico, you can do," said Borlaug, "and you can do it in half the time." Big talk is commonplace among agricultural developers. The thing that is unique about Norman Borlaug is not that he talks big but that he delivers. Nothing succeeds like success. And the special shipment of 1965, totalling 600 tons, proved a great success.

For the next crop, India ordered 18,000 metric tons of seed wheat from Mexico, the equivalent of two average shiploads. Together with seed from their own production, this was enough to plant 700,000 acres. The Pakistanis had enough for 600,000 acres. This was the year of the great drought on the Indian subcontinent. But the Mexican wheats did well. Under farm conditions, with proper cultural practices, they outyielded the native wheats by a factor of 2 or 3 or 4, sometimes even more. Standing three feet tall instead of four or five, they took up enormous amounts of soil nutrients and still stood erect.

Borlaug had been euthusiastic about the wheat development program in India and Pakistan from the first. Early in 1966 he told Secretary Amir Ahmed Khan of the West Pakistan Department of Agriculture: "Your country could be meeting its own wheat needs by 1968, 1969, or 1970." To government officials trying to pry enough Food for Peace wheat out of the United States in order to feed a hungry populace, the promise seemed incredible.

Now a great debate arose in India and in Pakistan. The Mexican wheats had looked good, very good. Should a full and firm commitment be made to these wheats? The decision lay with the government administrators, who consulted the farmers, the extension service, the production scientists, the economists, and the sociologists. Counsel was divided. The farmers wanted the wheat. But many of the scientists were dubious about staking so much on a wheat so new, subjected to such limited testing. Suppose there should be an outbreak of some plant disease, to which the new wheats were susceptible, and the whole crop were lost? For a nation on the threshold of hunger, the margin for experimentation was too thin. The cultural practices recommended for the Mexican wheat were far beyond the experience of the Asia scientists. Where would the necessary fertilizer come from? Could farmers be taught to fertilize and irrigate properly? The Mexican wheats produced relatively little straw; how would the bullock be fed? The color of the wheat was red, while the Indians perferred white. Baking qualities were not the preferred ones. With abundant supplies, the price would be driven down. And so on.

The scientists were problem-prone. They felt an unvoiced concern about their own professional status. If such high-yielding wheat was possible, why hadn't they produced it themselves? Borlaug, speaking in April of 1968 at a New York symposium on Strategy for the Conquest of Hunger, commented thus: "The scientist fears change because he is in a relatively privileged position in his own society. If there is no breakthrough in yield he will not be criticized. But if he makes a recommendation and something goes wrong, he may lose his job."

Various intramural battles developed. The fertilizer supply was limited. The economists wanted to use the supply heavily on the new Mexican wheats; the sociologists wanted to dole out small amounts to the largest possible number of farmers. Borlaug insisted on heavy rates of fertilization for his wheats, both because more wheat per ton of fertilizer could thus be obtained and because of the demonstration effect. He won, over strong protest.

In the end, the victory went to those who favored the Mexican wheats. Pakistan imported 40,000 metric tons in 1967, the equivalent of four shiploads, enough, with the seed they themselves had grown, to plant three million acres. The promotional program was tremendous. There were demonstration plots all over the land, some 30,000 or 40,000 altogether, contrasting the native with the Mexican wheats. Weather was good and yields from these wheats were heavy. In Pakistan the new wheats occupied 20 percent of the total wheat area and produced 42 percent of the total crop. In India the corresponding figures were 18 percent and 36 percent. The total production of wheat in Pakistan exceeded the previous record by approximately one-third. Pakistan met her own need for wheat for the first time within memory.

Further expansion of acreage in these wheats occurred in 1968-69 when India seeded 13 million acres and Pakistan 7 million. Mexican wheat varieties are being grown on an area in foreign countries that is 15 times as great as the entire area sown to wheat in Mexico. This level was reached only six years after the first samples, measured in grams, were received for trial.

The doubters say that the recent great performance of the Mexican wheats in India and Pakistan was due to good weather. But this cannot be a full explanation. Turkey also had some Mexican wheats. In 1967, Turkey experienced the worst weather in 30 years. Yet the Mexican wheats out-yielded the native varieties by better than 2 to 1.

One of the most convincing barometers of the farmers' enthusiasm for the new wheats is the price of seed stock. Jerry Eckert of the Ford Foundation says that in 1967 the price of standard Mexipak seed rose to more than twice the official price. It was necessary to guard the seed; on one occasion a robber held a knife at the watchman's throat while his confederate carried off the seed stock for sale to farmers in the black market. Borlaug says that seed of one new white grain variety sold for $3.00 per pound, about 100 times the going rate for ordinary wheat. Another report from India in the summer of 1968 quoted the black market price of a new variety at $60 a pound. A few heads of a very new but unproven variety were taken from the wheat nursery and sold for $14.00 a *gram*. This calculates out to $600 per pound.

There is one very precious thing about the wheat experience in Asia. The new wheats were called "The Mexican Wheats," not "The Rockefeller Wheats" nor "The American Wheats," though Rockefeller has supplied the money and the technology was essentially American. A new wheat, resulting from crossing one of the Mexican varieties with a native Pakistani wheat, was called "Mexipak." The Rockefeller people had the grace and wit to buoy up the Mexicans, the Pakistanis, and the Indians rather than to claim credit for themselves. By so doing, they increased the acceptability of the new wheats abroad and elevated the morale of the Mexicans. As any good teacher knows, the multiplication of knowledge depends on students themselves becoming teachers.

The Mexican wheats had a multiplier effect on other crops. Almost concurrently with their adoption came the increase in the new "miracle rice," IR-8, produced at the International Rice Research Institute at Los Banos in the Philippines. Like the new wheats, the new rice is short-strawed, capable of standing erect when heavily fertilized, a voracious feeder, widely adapted. The techniques for developing the miracle rice were modeled on those used by Borlaug on wheat. These two cereal grains are the backbone of the world's food supply. Both have been immensely improved. Together they have touched off a transformation in the growing of crops, a "green revolution."

With these new high-yielding grains farmers are motivated to buy more fertilizer. This puts pressure on the farm supply business. The availability of fertilizer in Pakistan is twice that of two years ago and several times that of 1960; it is expected at least to double again by 1970.

Irrigation becomes profitable with the new crop varieties. In the Punjab of northwest India, where ground-water is near the surface, farmers have recently put down thousands of private irrigation wells, at a cost of $1,000 to $2,500 each. Operation of these wells calls for installation and maintenance of electric or internal combustion motors—more skills to be learned. Growing two crops a year, an increasing practice in the tropics, requires rapid harvest and seed bed preparation for the next crop. This is more than can be expected from bullocks, so the tractor makes its appearance. Until recently, tractors were piling up at the end of the production lines in India; buyers were few. Today tractors are being loaded directly from the production line for delivery to farms and there is a waiting list for the output of the next two years. Insecticides are now profitable and must be purchased. Credit is necessary for long-term investment and current production, so farmers learn to borrow—and repay. Improved roads, storage, and mills are needed, requiring added investment. Farmers are motivated to read the labels on the fertilizer bag and on the insecticide package, so learning is elevated in status. With his now larger income the farmer can buy some consumer goods like radios and motorbikes. Gradually he moves out of traditional subsistence agriculture into the exchange economy.

MYTHS DISPELLED

Among the casualties of the green revolution were a number of myths. One of these was the belief that illiterate farmers are unresponsive to opportunity. "They may be illiterate," says F. F. Hill of the Ford Foundation, "but they can figure."

Another myth is the notion that peasant farmers respond in perverse fashion to economic incentives. "If returns per acre are increased, they will grow less wheat;" went the old cliche, "they will find it possible to meet their simple income needs without working so hard." This was part of economic folklore in Asia for a long time, and worked its way into agricultural policy. Artificially suppressed prices for wheat were supposed to keep food prices low for the consumer and at the same time place a mandate over the farmer to produce at a maximum. Neither of these things happened. With a gargantuan heave, the Indians and the Pakistanis threw off this myth. The price of wheat was increased. This, together with the promise of high yields, gave strong economic incentive to increase wheat production, to which the farmers responded in thoroughly orthodox fashion.

Another myth, popular among Westerners, was that Indian and Pakistani officials couldn't make anything move. But, with the right techniques in hand, the officials helped their farmers move even faster than the "impossible" schedule set up for them.

Yet another myth was the belief that the proper fulcrum for economic development was industry. Agriculture, it was thought, could hardly be the originator of change. But the green revolution, agriculture based, touched off a series of changes that stimulated industry: fertilizer, machinery, fuel, transportation, processing. The impetus came from agriculture.

One more. It had been widely believed that private industry, relying on the profit motive, would be an impediment to economic development; government, it was thought, must supply the needed goods and services. But the green revolu-

tion advanced at a rate more rapid than government could readily service. The pressure for fertilizer and insecticide became so great as to weaken and overcome the ideological commitment to government-run industry.

Much more is underway in Asia than the adoption of new wheat varieties.

The green revolution has profound influence on established institutions. The terms for the division of the crop between landlord and tenant are no longer appropriate and need changing. With double-cropping the seasonal rhythm of rural activity is transformed. There is no economic or social change more profound than the change from self-sufficiency to an exchange system.

Not all the changes are welcomed. Some farmers are demoted from tenants to laborers as the landlords themselves undertake the now profitable farm operation. Some laborers are unemployed as a result of mechanization. The forward surge of wheat and rice disturbs the price and profit relationships with cotton and other crops, necessitating changes in resource use. The gap between the lower and the upper rung of the economic ladder widens. Heavier production means lower prices. Problems of shortage may be replaced by problems of surplus which, though the more tractable of the two, are problems nonetheless. Not all people are advantaged by the new developments. The disadvantaged and the dispossessed form the nuclei of dissident groups.

The technologist, whether he works with wheat or tractors or chemicals, is the engineer of social change. And there is no safe prediction as to just where social change may lead. It is a venture taken without certainty as to direction or destination.

But these thoughts, if dwelt upon, can immobilize the will, deify the existing state of affairs, and negate every proposed change. Anyone who has visited the less-developed parts of the world and has seen hunger at close range will hesitate not a moment in trying to increase the availability of food. If this effort brings with it some associated problems, they are next in line for treatment.

Success with wheat and rice has given a great lift to the spirit. Research people have had their sights elevated with respect to what is possible. The extension service now has new knowledge to extend. The bureaucracy has been rejuvenated. This improved outlook is what Norman Borlaug had sought; he was convinced from the first that economic development is as much psychological as technical. "I believe in approaching this transformation," he said, "just as an aggressive football coach, such as Bear Bryant, would approach building a winning combination out of a football team that had not won a game for the last 20 years, and one in which the team throughout its history has been playing only a passive, defensive, defeatist type of game." Borlaug believes dramatic yield increases are needed to bring about change. "Yield increases of 15 to 20 percent will convince no one. Demonstrations showing increases of from 200 to 600 percent, that is, from 10 bushels to 75 bushels per acre, as have been widely demonstrated in Pakistan and India the past two years, have caught the peasant's imagination, built a fire or set a bomb under the politician, and have triggered off an agricultural revolution of fantastic proportions."

Borlaug's strategy for crop improvement is quite different from that of conventional foreign assistance officials, who, as he sees it, lean toward big budgets and scattered programs which tend to be staffed by mediocre scientists. Borlaug believes in small teams of highly competent men who, by their dramatic accomplishments, stimulate the indigenous scientific community and command support from high officials.

What next for Norman Borlaug? First priority is to help push through, ahead of schedule if possible, the agricultural revolution underway in India and Pakistan. And to help undergird that revolution with new and better wheat varieties, with improved research, and with better adult education. Borlaug and his associates are assisting in transforming the wheat-breeding programs of India and Pakistan into aggressive, productive efforts that will be able to cope with the new rust races certain to appear.

And, concurrently, the objective is to set up the wheat revolution in Turkey and Afghanistan, countries now on the verge of a breakthrough. And to get going in those countries that are just starting: Argentina, Chile, Iran, Morocco, Algeria, Tunisia, Egypt, Iraq, and Syria.

Additional tropical research centers are being built for Colombia and Nigeria, fashioned after the Mexican and Philippine pattern.

Application of now-proven techniques to corn, potatoes, cotton, sorghum, and millet are already far along. For the long look ahead, Borlaug is working on a new plant altogether which is called "triticale," a cross of two distinct species, wheat and rye. It would be the world's first wholly man-made crop. What good would it be? "We want to see if we can do it," says Borlaug. "And it might be a good yielder."

Does the green revolution indicate that the war against hunger is won? By no means. All that can be claimed is that progress has far exceeded the expectations of a few years ago and that the per capita food supply in the less-developed countries is, for the time being, somewhat increased. No good student of the world food situation would claim that the problem of hunger has been whipped. Most would agree that valuable time has been won, time that *should* be wisely used in checking the rate of population growth. Present growth rates, if extrapolated, take on astronomic proportions. The only way it makes any sense to talk about solving the world food problem is to envision and achieve some degree of control over population numbers.

How does it feel to be at the vortex of a technological revolution in agriculture? "Great!" replies Borlaug. Then his face clouds. "It *would* be great if population growth would slow down."

* * *

This story began with Fabre's quotation contrasting cultivated fields with battlefields, comparing wheat with war. We return to that note.

Throughout this story runs a hopeful and transcendent theme—the triumph of peaceful efforts at human betterment over the destructive effect of war. It was during World War II that the Mexican wheat project was launched. It was from the wreckage of post-war Japan that the needed germ plasm came. The truck convoy somehow made it through the hate and violence of Watts. The war between India and Pakistan broke out while the new wheat, destined for both of them, was afloat. Yet the wheat arrived and the farmers set to work in an undramatic fashion, improving and increasing crop production.

The antecedents for Borlaug's new wheat come from both sides of the Iron Curtain. The new rice is planted on both sides of the Bamboo Curtain. Trainees at the Mexican wheat improvement center work together amicably, Pakistanis and Indians, blacks and whites. There is about agriculture some strange and wonderful unifying principle. Science is oblivious to skin color, ancient animosities, and ideological confrontations. It may become the bridge of understanding.

To be a hunger fighter is to work in a cause conducive to peace. The victory over hunger may yet be won. The winning of it may heal the heart as well as nourish the body. This thought helps sustain those who work to provide our daily bread.

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